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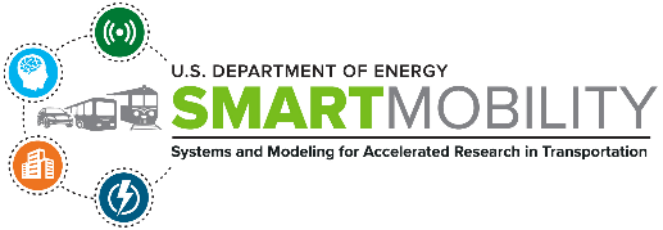

OPTIMIZING DRONE DEPLOYMENT
FOR MORE EFFECTIVE MOVEMENT OF GOODS

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U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Argonne NATIONAL LABORATORY · BERKELEY LAB · INL Idaho National Laboratory · NREL · OAK RIDGE National Laboratory · Pacific Northwest

OVERVIEW

Timeline

- Project start date: October 2020
- Project end date: October 2022
- Percent complete: 25%

Budget

- Total project funding: $1150K
  - INL: $900K
  - ANL: $250K

Barriers and Technical Targets

- Understanding energy impacts and performance of new technology
- High risk to develop and deploy advanced vehicles and infrastructure

Partners

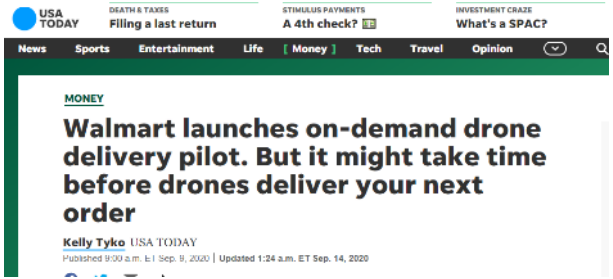
- Idaho National Laboratory
- Argonne National Laboratory

Collaboration with Carnegie Melon University

RELEVANCE

Quickly changing opportunity

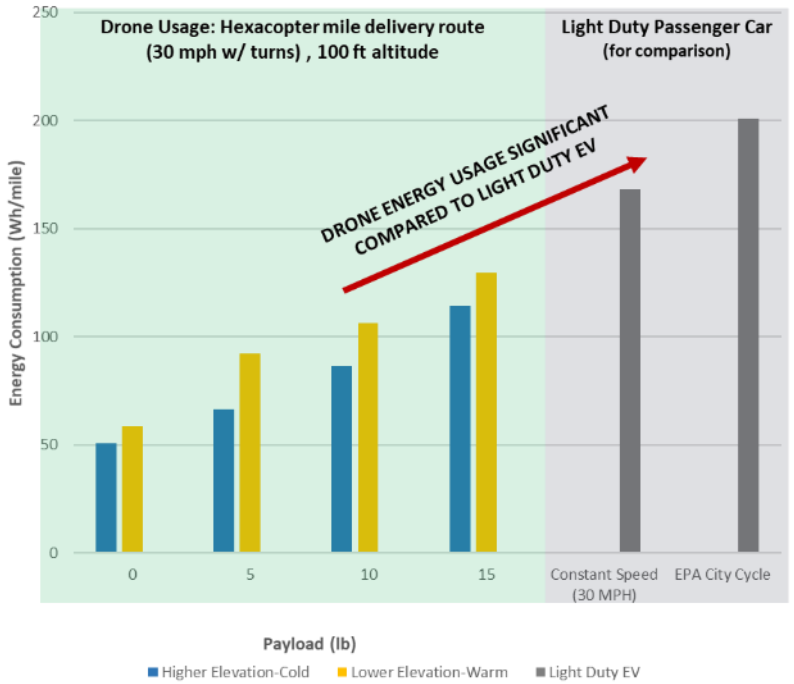
- Dramatically increasing demand for local, fast delivery
- Technology changes to support easier and automated deliveries
- Strong industry interest in drones
- Regulations actively changing
- Unknown impacts on current systems



RELEVANCE

Energy is not trivial

- Initial tests indicate that delivery can take significant energy
- Influenced by drone type, package weight, temperature



RELEVANCE

Need for more open data and independent review on drones

Research Needs

- Need for basic data / operations
- Data needed to build physics models
- Component-level breakdown

Industry Needs

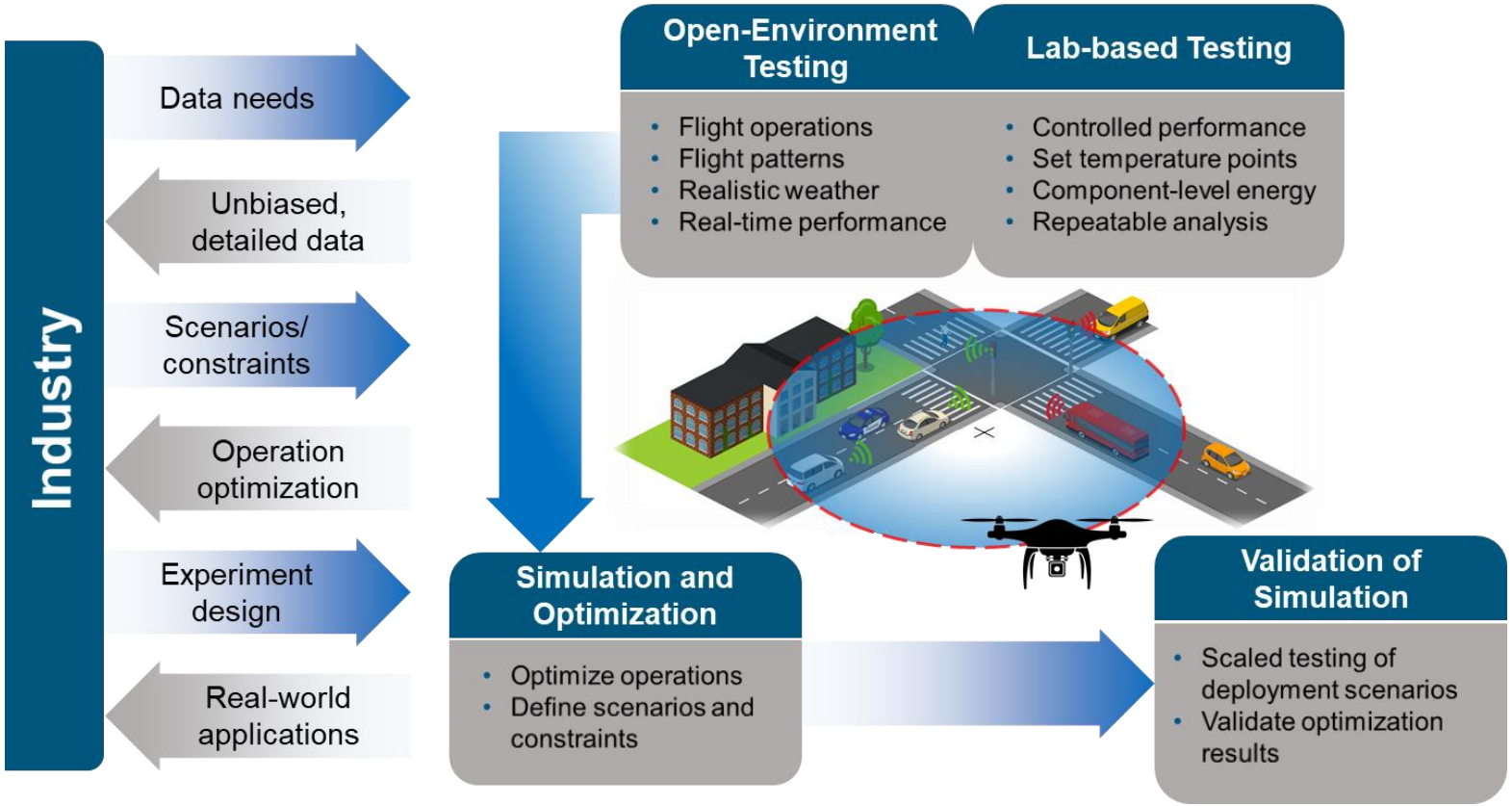
- Operations impacts
- Technology options
- Optimal fleet management techniques

RELEVANCE

Sample Insights

- Total energy for drone deliveries
- Efficiency and throughput of total delivery system
- Drone types for different missions and conditions
- The effect of environmental conditions (e.g., ambient temperature) on the energy efficiency and mission capabilities
- Impacts of operation changes such as ascent mode, turn methods, hovers
- Impacts of regulations (such as Restricted flight paths, flight heights, speed, size, etc.) in terms of time, speed and energy
- Understanding component energy use
- Strategies for effective drone fleet sizing, dispatching, and charging
- Optimizing by mission profiles and types of business

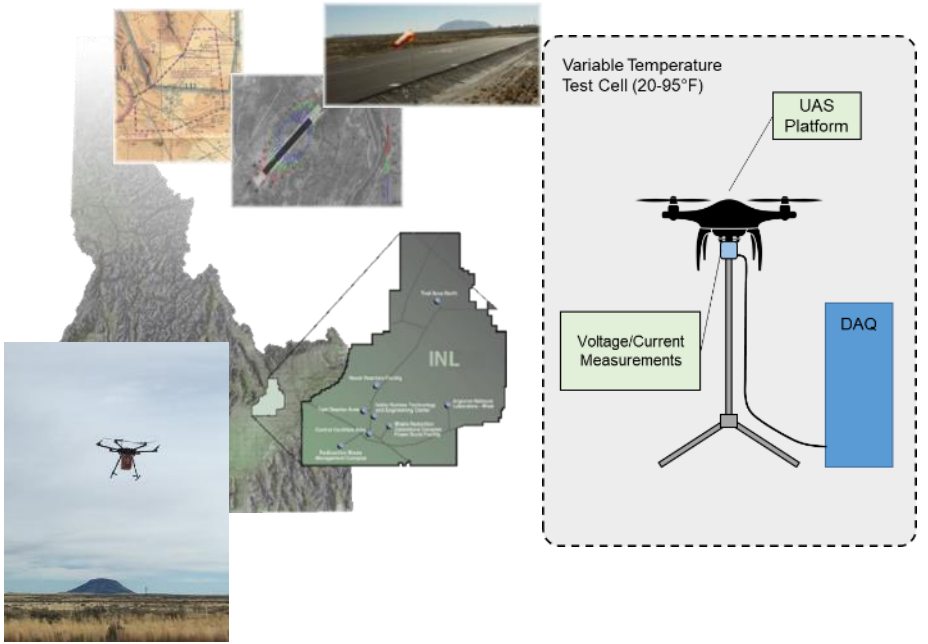
APPROACH


Industry
Data needs
Unbiased, detailed data
Scenarios/ constraints
Operation optimization
Experiment design
Real-world applications
Open-Environment Testing
Flight operations
Flight patterns
Realistic weather
Real-time performance
Lab-based Testing
Controlled performance
Set temperature points
Component-level energy
Repeatable analysis
Simulation and Optimization
Optimize operations
Define scenarios and constraints
Validation of Simulation
Scaled testing of deployment scenarios
Validate optimization results

APPROACH

Drone Testing

- Open Air Testing
  - INL UAS runway
  - Operations
  - Varied Conditions
- Lab Testing
  - Argonne National Lab test cell
  - Components
  - Force Feedback
  - Temperature
- Data provided to models for optimization, labs, industry



APPROACH

Optimization Modelling

- **Model for operations and comparisons**
- **Optimization based on Integer programming.**
- ***Objective function*: Minimize fleet energy consumption for effective delivery of goods (timely and cost-effectively).**

***Input data*:**

- Package demand: Daily package demand by size, weight, origin location
- Time: Delivery time windows of each package.
- Customer: customer locations and orders
- Drone information: Number of drones in the fleet, characteristics of each drone.
- Flight parameters (weather, operation options, etc.)

Model outputs:

- Delivery route: Set of alternative delivery routes varied by flight maneuvers, package delivery mechanisms, flight trajectory, flight paths, etc.
- Energy consumption based on flight maneuvers, drone weight, speed, trajectory, weather conditions and other drone parameters considered for energy calculation

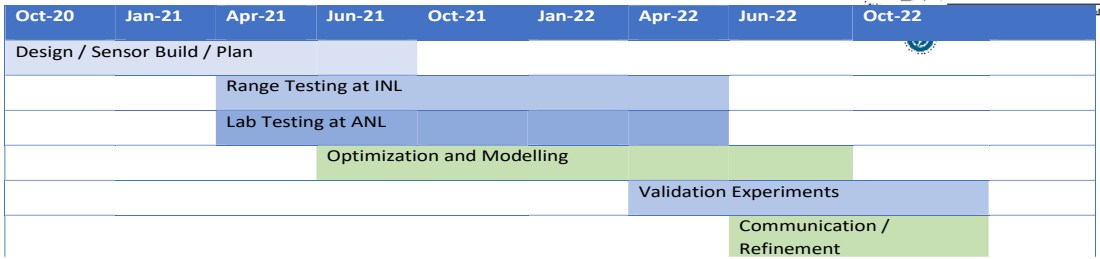
APPROACH

Validation / Demonstration

- Open Air Demonstration of techniques
  - INL UAS facilities
  - Multiple drones / scenarios.
- Validation of optimized techniques and methods in real-world setting
- Communication of results

APPROACH

Timing / Milestones

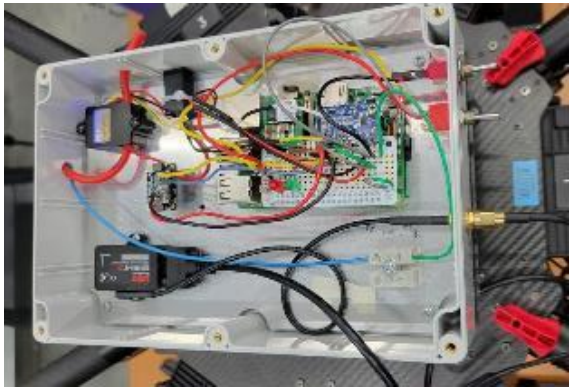


Milestone Name/Description*	End Date*
Develop detailed test plan for drone testing. Design sensors and create data acquisition plan. (Task 1) (INL,ANL)	12/31/2020
Identify primary scenarios for drone deployment using industry feedback (Task 1). Identify constraints and structure for optimization modelling. (Task 2) (INL)	3/31/2021
Complete environmental and energy testing of at least one drone in the open-air environment at INL. (Task 1) (INL)	6/30/2021
Complete energy testing of at least one drone in the controlled lab environment at ANL. (Task 1) (ANL)	6/30/2021
Complete additional drone testing and perform analysis of initial test data to demonstrate impact of drone operations on energy and throughput. (Task 1) (INL, ANL)	9/30/2021
Complete gathering key data for optimization routines and demonstrate optimization methods on partial data. (Task 2) (INL)	12/31/2021
Complete system optimization model for drone deployment in two scenarios and compare operation profiles. (Task 2) (INL)	3/31/2022
Complete a report on component energy from ANL drone testing. (Task 1. (ANL)	3/31/2022
Validate the optimization techniques by performing physical delivery experiments in the open-air environment at INL using at least 2 types of drones and 2 scenarios. (Task 3) (INL)	6/30/2022
Complete the analysis of data and the optimization scenarios. Provide a report of results and complete a draft journal article. (Task 3) (INL)	9/30/2022

PROGRESS

Drone Testing

- Sensor platform for detailed data recording of energy and motion
  - Design
  - Purchase
  - Assembly
  - Programming
  - Testing



Current, Voltage, IMU (Motion), GPS, Temperature, Pressure, Humidity, Wind direction and speed. Recorded to local computer.

PROGRESS

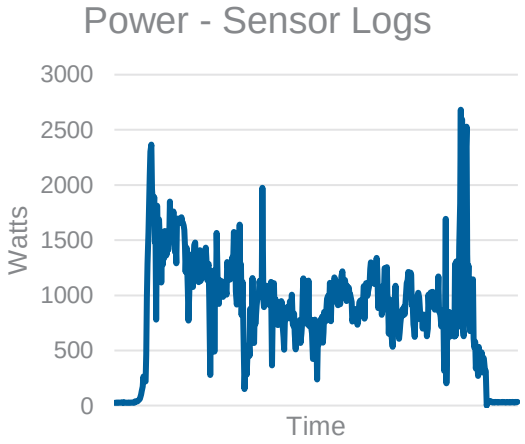
Drone Testing

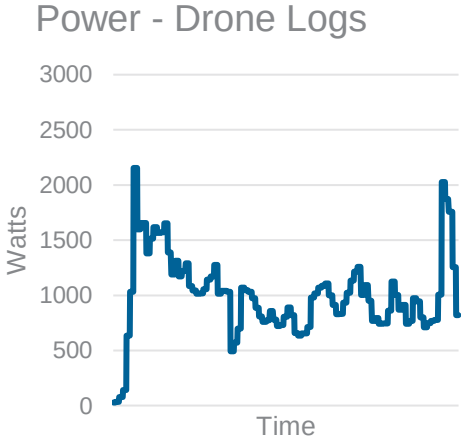
- Initial Tests under-way
- Weather and technical issues reflect drone operational conditions

PROGRESS

Drone Testing

- Good match with sensor and log reading
- External sensors much more exact and responsive
- Data reflects impacts of wind on performance





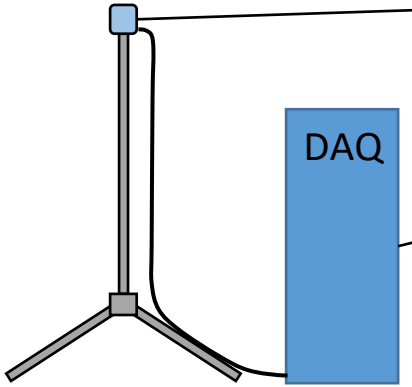
PROGRESS

Drone Testing

- DJI Matrice 600 Pro Acquired for Testing
- Nordbo Robotics NRS-6050-D80 sensor for lift force feedback
- Energy consumption instrumentation underway
- Detailed test plans complete

DJI Matrice 600 Pro

Nordbo Robotics NRS-6050-D80

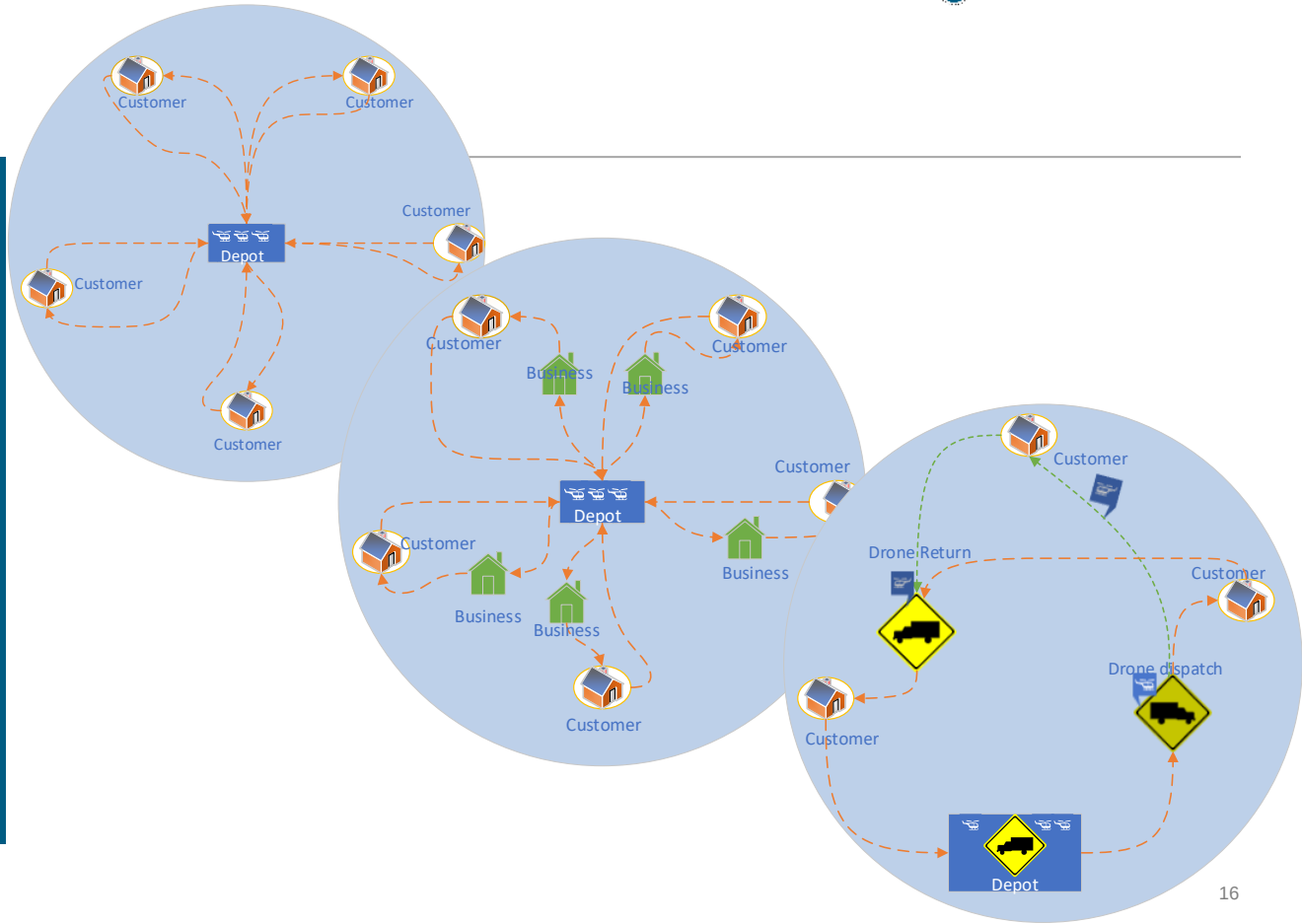


Data Acquisition System (DAQ)

PROGRESS

Optimization

- 3 Major Scenarios Developed:
  - Direct Delivery
  - Delivery as a service
  - Parcel Delivery Support



PROGRESS

Optimization

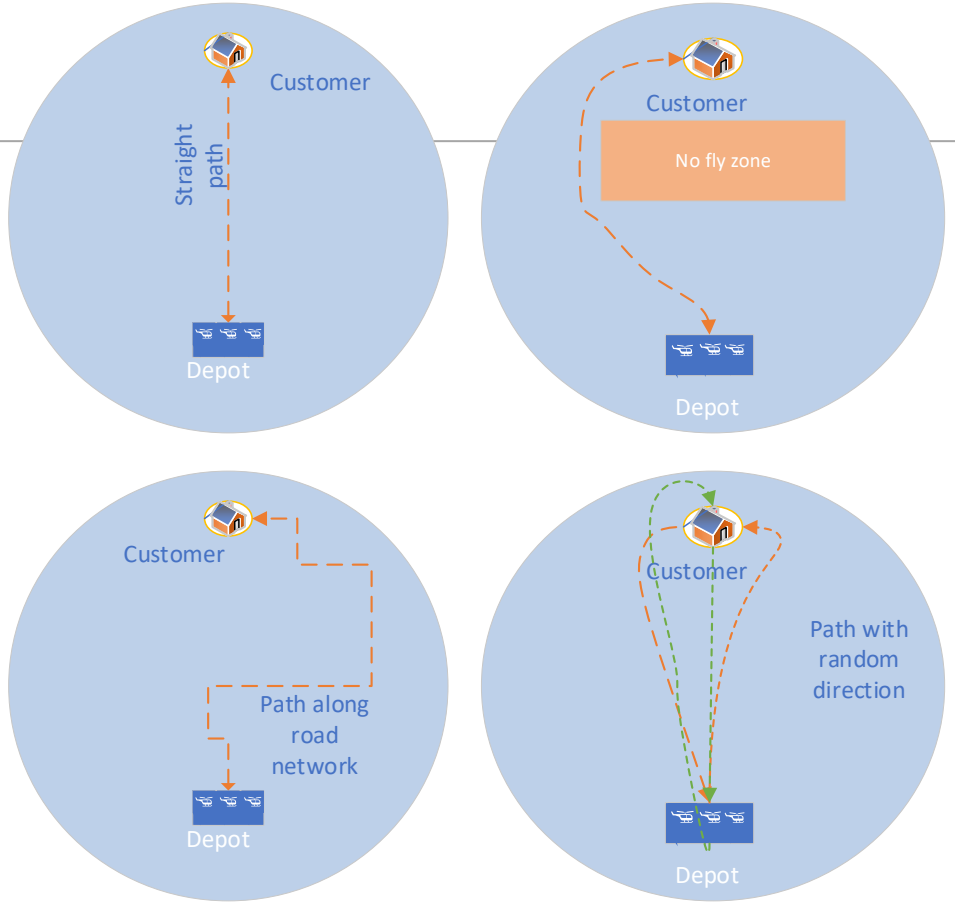
- **Variable options and operation impacts**

	Options		
Drone specification	Hybrid Drone (Wing)	Rotary Hex-Copter (Matrice 600)	Mid-sized Rotary (TBD)
Drone fleet design	All drones of same type with same specification	Drone type can be mixed – Fixed number of each drone	Unlimited drone supply based on demand.
Routing Method	Direct Line Varied Approach Paths	Over-Road Flights	Increased No-Fly Zones
Delivery method	Hovering	Landing	
Cruise Height	100 foot	150 foot	200 foot
Cruise Speed	30 mph	45 mph	70 mph
Turn style	Full stop, turn	Rounded turn	
Ascent style	Straight up	45 Degree angle	
Weather			
Wind speeds	O mph	5 mph constant	15 mph constant
Temperature	32 degrees	72 degrees	95 degrees

PROGRESS

Optimization

- **Routing methods have large impact on energy and throughput.**
  - **Straight-line**
  - **Increased No-Fly Zone avoidance**
  - **Follow Road Network**
  - **Random path approach**



FUTURE RESEARCH

Continued Testing and Integration

- **Executing Test Plan**
- **Collaboration with more partners**
- **Obtaining and testing additional platforms**
- **Optimization development**
- **Communication**

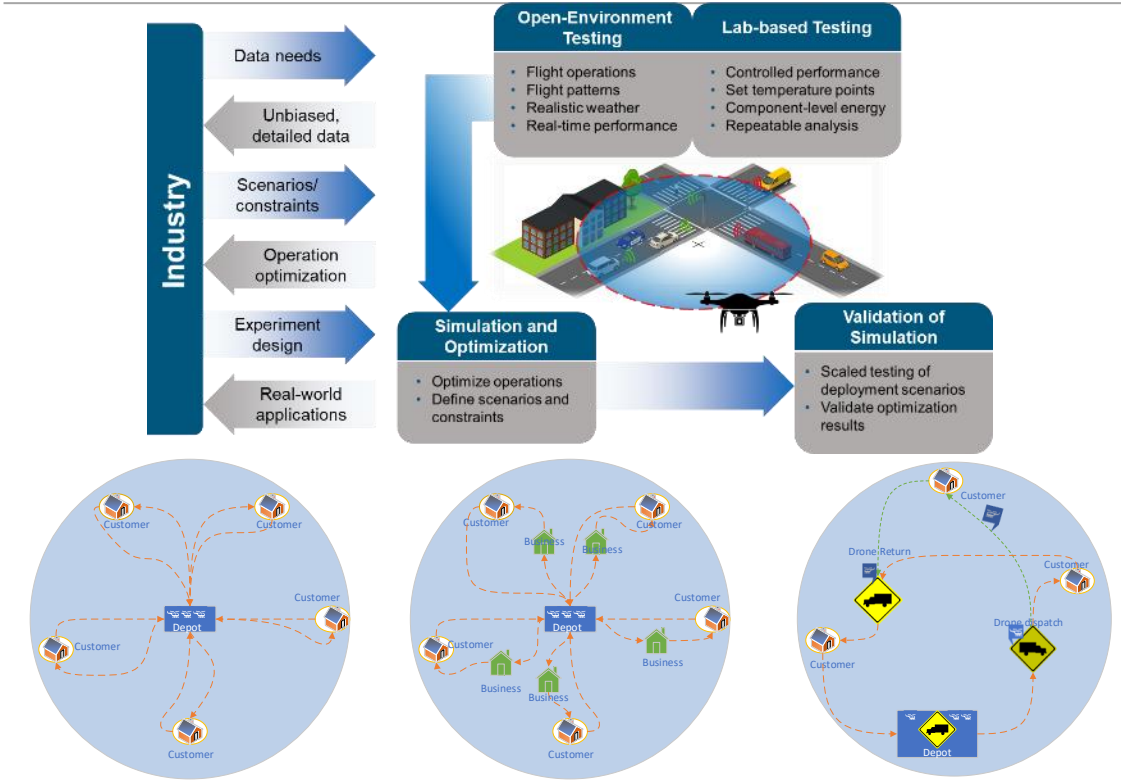
- Challenges:
  - Obtaining relevant airframes
  - Overcoming technical challenges
  - Obtaining relevant comparison data
  - Targeting greatest industry needs

*Any proposed future work is subject to change based on funding levels.

SUMMARY

Critical Data for a Quickly Developing Field

- Key focus on the needs of a growing industry
- Detailed testing to inform critical models
- Optimization to help inform industry
- Critical validation and communication



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MOBILITY FOR OPPORTUNITY

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